P1 1174908

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

May 25, 2004

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE.

APPLICATION NUMBER: *60/498,945*
FILING DATE: *August 29, 2003*
RELATED PCT APPLICATION NUMBER: *PCT/US04/10789*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

E. Bornett

E. BORNETT
Certifying Officer

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Please type a plus sign (+) inside this box → +

Express Mail Label: EL995079192US

PTO/SB/16 (8-00)
Approved for use through 10/31/2002. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

16424 U.S. PTO
60/498945

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Cristina	Gomila	Princeton, New Jersey USA
Joan	Llach	Princeton, New Jersey USA

☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

AUTOMATIC FILM GRAIN MODELING IN THE FREQUENCY DOMAIN

CORRESPONDENCE ADDRESS

Direct all correspondence to:

☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*

Type Customer Number here

OR

☒ Firm *or* Individual Name	Joseph S. Tripoli - Thomson Licensing Inc.				
Address	PATENT OPERATIONS				
Address	P. O. BOX 5312				
City	PRINCETON	State	NJ	ZIP	08543-5312
Country	USA	Telephone	609-734-6834	Fax	609-734-6888

ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification *Number of Pages* 8 ☐ CD(s), Number

☒ Drawing(s) *Number of Sheets* 5 ☐ Other (specify)

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT *(check one)*

☐ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fees

☒ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 07-0832

FILING FEE AMOUNT ($) 160

☐ Payment by credit card. Form PTO-2038 is attached.

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____.

Respectfully submitted,

SIGNATURE Guy H. Eriksen

Date 08/29/03

TYPED or PRINTED NAME GUY H. ERIKSEN

REGISTRATION NO. 41,736 *(if appropriate)*

Docket Number: PU030259

TELEPHONE (609) 734-6807

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

 Express Mail Label: EL995079192US

AUTOMATIC FILM GRAIN MODELING IN THE FREQUENCY DOMAIN

BACKGROUND OF THE INVENTION

Film grain simulation has been implemented in several commercially available products. It is often used to blend a computer-generated object into natural scenes. Cineon (trademark of Eastman Kodak Co.) was apparently the first digital film application to implement grain simulation. Cineon produces very realistic results for many grain types but requires manually setting the film grain parameters.

Another commercial product allowing the simulation of film grain is Grain Surgery from Visual Infinity Inc., which is used as a plug-in of Adobe ® After Effects ®. Their approach seems similar to that described in US Patent No. 5,629,769 issued to R.E. Cookingham and P.J. Kane (hereinafter Cookingham et al.) entitled, "Apparatus and method for the measurement of grain in images". Cookingham et al. suggests generating synthetic grain by filtering a set of random numbers. This product provides algorithms allowing film grain generation with user interaction, but also allowing non-aided film grain simulation provided a grainy source as reference.

Motion picture film typically contains signal-dependent noise resulting from the physical process of exposure and development of the photographic film, which originates a characteristic quasi-random pattern, or texture, caused by the physical granularity of the photographic emulsion. Alternatively, signal-dependent noise can also be the result of subsequent editing of the images. We will refer to this signal-dependent noise as grain or film grain.

A similar pattern might be simulated for video compression purposes. In previous disclosures, we proposed a method for encoding film grain as supplemental enhancement information for a coded sequence. More specifically, we proposed to filter grain out of images before compression, then transmit compressed video together with a message containing information about original grain, and let the decoder restore original grainy appearance of images by simulating film grain based on the content of the message.

To the best of our knowledge, no prior art references exists describing non-aided methods that characterize the grain of a reference source.

SUMMARY OF THE INVENTION

In accordance with the principles of the present invention, we disclose a method that allows modeling the film grain in the frequency domain. Such method can be used to automatically parameterize film grain, or to initialize a user-aided process of film grain modeling.

A specific application of this invention concerns the representation of film grain, for which the method estimates: (1) the noise variance that models the perceived intensity of the grain; and (2) the cut frequencies that characterize the size of the grain when filtering in the frequency domain. The film grain parameters estimated by this method could be conveyed in accordance with the H.264 I MPEG-4 AVC standard in an SEI message allowing film grain reinsertion at the decoder end.

DETAILED DESCRIPTION

In accordance with the principles of the present invention, we disclose a method for allowing automatic modeling of signal-dependent noise in the frequency domain. A specific application of this invention concerns the representation of film grain in accordance with models previously disclosed in prior patent applications. Formulation of this model is as follows:

$$I_{grain}[\,x, y, c\,] = I_{without\ grain}[\,x, y, c\,] + G[\,x, y, c\,] \quad , \tag{1}$$

where G[x, y, c] represents the simulated grain at pixel coordinates (x, y) and color component c. In the frequency domain, G[x, y, c] is computed as

$$G[\,x, y, c\,] = p * Q[\,x, y, c\,] + u * G[\,x, y, c-1\,]. \tag{2}$$

where parameter p is the standard deviation of the random noise and parameter u models the cross-color correlation among different color components. More in detail, Q[c] is a two-dimensional random field generated by filtering blocks b of NxM random values, which have been generated with a normalized Gaussian distribution N(0,1). The band-pass filtering of blocks b_N can be performed in the frequency domain as follows:

Step 1: Transform

```
B = DCT_NxM( b)
```

Step 2: Frequency filtering

```
for( y=0; y<N; y++)
  for( x= 0; x<M; x++)
    if ( ( x < LOW_HF  &&  y < LOW_VF )  ||
        x > HIGH_HF  ||  y > HIGH_VF )
      B[ x, y ] = 0;
```

Step 3: Inverse transform

```
b' = IDCT_NxM( B)
```

Finally, Q[c] is formed by mosaicing the filtered blocks b'. To reduce possible blockiness, the algorithm may introduce a last step in which a low-pass filter applies to block transitions.

Although M and N could take any value, most common implementations would likely use squared blocks of 16x16, 8x8 or 4x4 pixels. Note also that other transforms, such as the Fast Fourier Transform (FFT), could be used in steps 1 and 3, instead of the Discrete Cosine Transform (DCT) used in the equations.

In accordance to this model and in accordance with the principles of the present invention, one embodiment of the instant invention estimates:

The noise variance that models the perceived intensity of the grain (parameter p in equation (2); and

The horizontal and vertical cut frequencies (LOW_HF, HIGH_HF, LOW_VF, HIGH_VF) that characterize the size of the grain when filtering in the frequency domain.

Assuming there is no cross-color correlation (u=0 in equation (2)), the film grain parameters estimated by this method could be conveyed in accordance with the H.264 I MPEG-4 AVC standard in an SEI message allowing film grain reinsertion at the decoder end.

The following sections present the different processes used in accordance with the principles of the present invention:

1. Film grain extraction

In all cases, film grain parameterization requires as a first step to extract the film grain from the original source. When two versions of the original content are available, one with film grain and another without, a perfect extraction of the film grain is possible by subtraction, as illustrated in Figure 1. When the version without film grain is not available, a filtered version of the original source can be used as an estimate of the image without film grain, as illustrated in Figure 2.

In the latter case, however, the residual obtained by subtracting filtered from original images will provide film grain mixed with other fine details and textures removed by the filtering process. To avoid introducing a bias in the film grain modeling process, in one embodiment of the present invention, we propose an alternative extraction procedure, illustrated in Figure 3.

Through this procedure, the flat zones of the filtered images are detected prior to film grain extraction. Flat zones can be detected on a pixel basis or on a block basis with different criteria of flatness. In a particular embodiment, the algorithm would signal as flat zone any block of NxM pixels presenting a variance lower than a given threshold. Based on the flat zone detection, the algorithm outputs a mask differentiating between flat zones and non-flat zones. The extraction algorithm will use this mask to restrict the film grain extraction to the flat zones. Several images can be filtered and used as source of flat zones/blocks. To avoid running out of flat

zones/blocks from where to extract grain, the algorithm could pick the M flattest zones/blocks, for a required M.

The system of Figure 3 requires more memory bandwidth than the systems of Figures 1 and 2, because for each original image, a mask image signaling the flat zones is stored and accessed. However, it provides improved performance since it isolates the film grain from textured regions where other high frequencies might have been suppressed by the filtering process.

2. Film grain characterization

Following the film grain extraction, the system proceeds to the film grain characterization. In accordance with one embodiment of the present invention, film grain characterization in the frequency domain is comprised of two blocks, as illustrated in Figure 4.

2. 1. Estimation of the noise statistics

Some characteristics of the film grain can be well represented by the statistical values of the grain image. One step of film grain characterization is computing the statistics of the noise, represented by Block 1 in Figure 4. These values may comprise both low- and high-order statistics such as mean, variance, skewness or kurtosis. In the particular implementation of grain simulation presented in [3,4], only the standard deviation is used to determine the intensity of the grain assuming zero mean. Following the notation introduced in equation (2), parameter p is estimated as:

$$p = \sigma_{grain} \tag{3}$$

Although several images may be present at the input of the noise statistics computation block, it is not mandatory that all their pixels to be used in the estimation. In a particular embodiment, the statistics may be computed by combining estimates on different regions of the grain images to facilitate hardware implementations (for example, parallelization).

2. 2. Estimation of the spatial correlation in th fr qu ncy domain

Block 2 of Figure 4 is the estimation of the spatial correlation in the grain images, which will convey a representation of the shape and size of the film grain. In accordance with the principles of the present invention, we describe a non-aided method that estimates the cut frequencies characterizing the spatial correlation of the film grain in the frequency domain. These frequencies may be used as parameters of the earlier-mentioned SEI message which would allow film grain reinsertion at the decoder end.

A particular implementation based on the DCT of squared blocks of NxN pixels is presented in Figure 5. In the first step, a block of NxN pixels is extracted from the input grain images previously obtained. Then, the DCT of the block is computed and the resulting coefficients are stored in the block stores. Finally, a condition is assessed to decide if more blocks are needed. In the trivial implementation, all input blocks are stored in the block stores, but other approaches could be used in order to reduce memory requirements or computational load. To cite a few, a possible implementation would stop processing once a certain number of blocks was reached, while another implementation could rely on the number of blocks extracted from each grain image in order to decide when stop.

Once the block stores is full, a mean block $\mathbf{B}_{mean}$ is computed by averaging frequency coefficients from all blocks in the block stores. Assuming K as the number of blocks in the block stores, the averaging process for the frequency coefficient at position [x,y] can be formulated as follows,

$$\mathbf{B}_{mean}[x,y] = \frac{1}{K}\sum_{i=0}^{K-1}\mathbf{B}_i[x,y] \quad (4)$$

In the next step, the algorithm computes the horizontal and vertical frequency vectors. In the block diagram of Figure 5, both processes are computed in parallel.

We have defined the horizontal frequency vector $\mathbf{B}_H$ as the vector resulting from averaging the N frequency coefficients of each row of $\mathbf{B}_{mean}$

$$\mathbf{B}_H[y] = \frac{1}{N}\sum_{n=0}^{N-1}\mathbf{B}_{mean}[n,y] \quad (5)$$

Similarly, have defined the vertical frequency vector $\mathbf{B}_V$ as the vector resulting from averaging the N frequency coefficients of each column of $\mathbf{B}_{mean}$

$$\mathbf{B}_V[x] = \frac{1}{N}\sum_{n=0}^{N-1}\mathbf{B}_{mean}[x,n] \qquad (6)$$

Based on the frequency vectors, the last step in the estimation of the spatial correlation of the film grain is detecting the cut frequencies in $\mathbf{B}_H$ and $\mathbf{B}_V$, if any. In the block diagram of Figure 5, these calculations are done in parallel. The procedure that extracts the cut frequencies for $\mathbf{B}_H$ in one embodiment of the present invention is disclosed below; however, it should be noted that the same procedure may also be used for $\mathbf{B}_V$.

The estimation of the cut frequencies is done as follows:

Step 1: low-pass filter the components of the frequency vector to avoid spurious peaks. In a particular implementation, this can be done by convolving the frequency vector with a filter of impulse response ***h[n]:***

$$\mathbf{B'}_H[n] = \sum_{i=1}^{n}\mathbf{B}_H[i]\mathbf{h}[n-i] = (\mathbf{B}_H * h)[n]$$

(7)

In the filtering process, it is desirable to avoid the influence of the DC term located at position 0 in the frequency vector. For example, a 3-tap linear filter with coefficients w_0, w_1, and w_2 should apply only to the coefficients with index $n \geq 2$:

$$\mathbf{B'}_H[n] = w_0 \cdot \mathbf{B}_H[n-1] + w_1 \cdot \mathbf{B}_H[n] + w_2 \cdot \mathbf{B}_H[n+1], \quad 2 \leq n < N-1 \qquad (8)$$

Step 2: compute the mean value of $\mathbf{B'}_H$ by averaging its components:

$$\overline{B}'_H = \frac{1}{N}\sum_{n=0}^{N-1} \mathbf{B}'_H[n] \tag{9}$$

Step 3: representing $\mathbf{B'}_H$ as a curve, compute its intersection points with the average value $\overline{B}'_H$, then:

If a single intersection point is found, the index n of the closest component in $\mathbf{B'}_H$ is chosen as the value of the horizontal high cut frequency; the horizontal low cut frequency is assumed to be 0.

If two intersection points are found, the indexes of the closest components are found for each one. The lowest value will correspond to the low horizontal cut frequency whereas the highest value will correspond to the high horizontal cut frequency.

If more than two intersection points are found, no spatial correlation is detected. The horizontal low cut frequency is assumed to be 0, and the horizontal high cut frequency is assumed to be N-1, indicating to the film grain simulation function that no frequency filtering is required to imitate the original grain.

The same procedure may be applied for the vertical frequency vector $\mathbf{B}_V$. At the end of both processes, the algorithm yields four cut frequencies (LOW_HF, HIGH_HF, LOW_VF, HIGH_VF) that allow characterizing both the size and the elongation of the grain. Elongated grain will result when LOW_HF ≠ LOW_VF and/or HIGH_HF ≠ HIGH_VF.

As an alternative approach, it is possible to constrain the grain to circular shapes. This implies that horizontal and vertical cut frequencies will be the same. In this case, vertical and horizontal frequency vectors ($\mathbf{B}_H$ and $\mathbf{B}_V$) are averaged to create single frequency vector (**B**). Then, the same procedure is used to estimate low and high cut frequencies.

PU030259

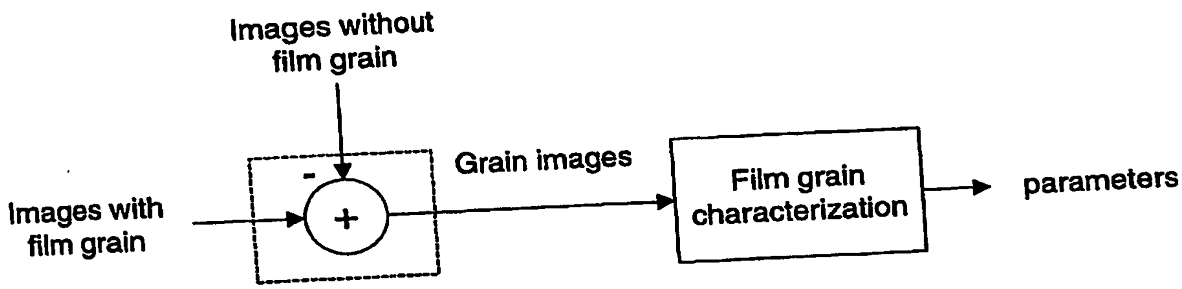

Figure 1. Film grain extraction.

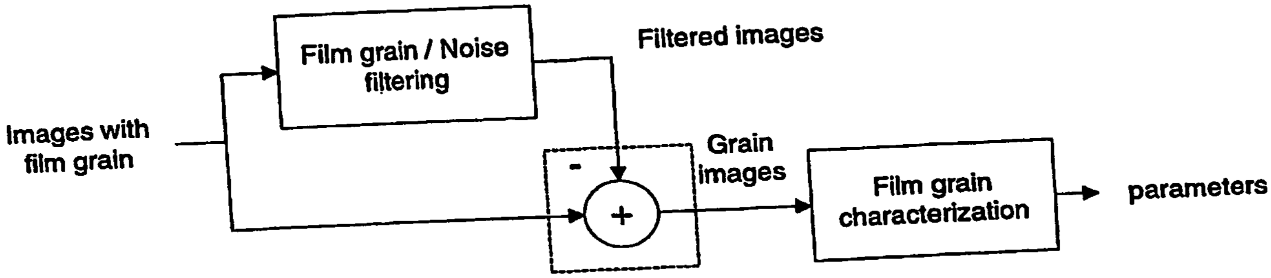

Figure 2. Film grain extraction.

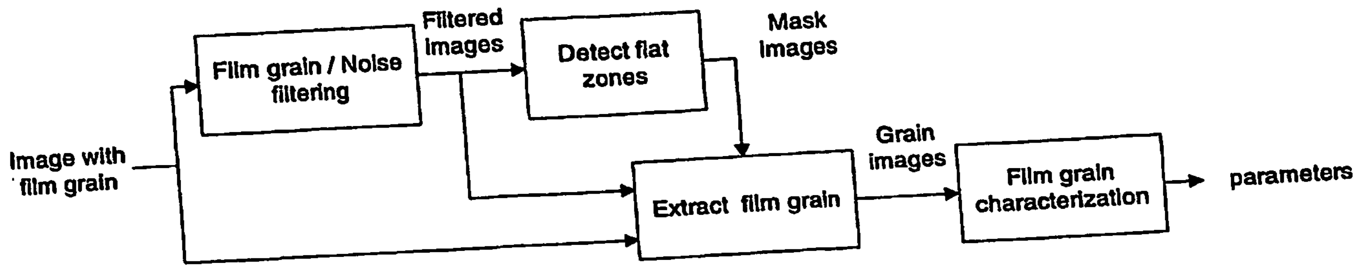

Figure 3. Film grain extraction.

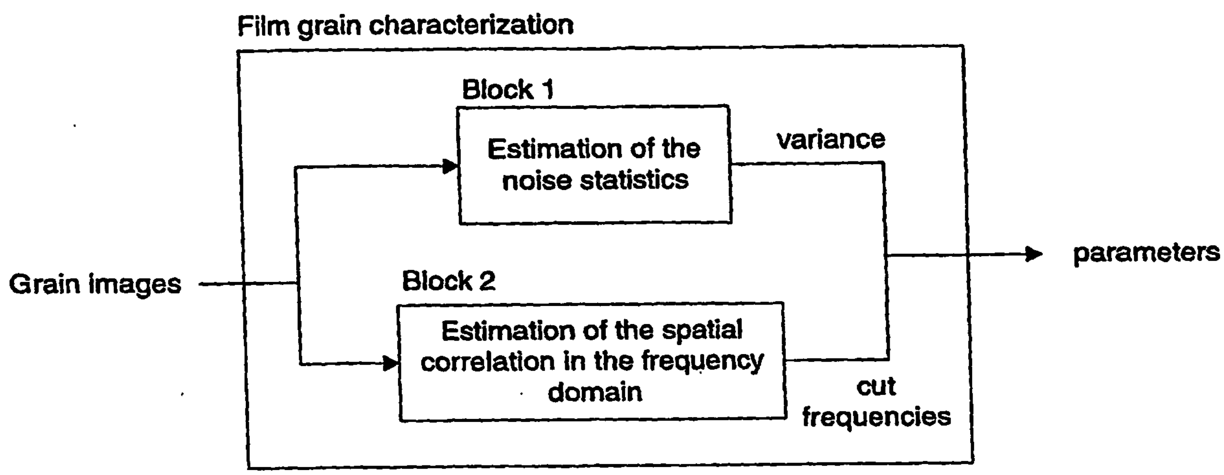

Figure 4. Film grain characterization.

PU030259

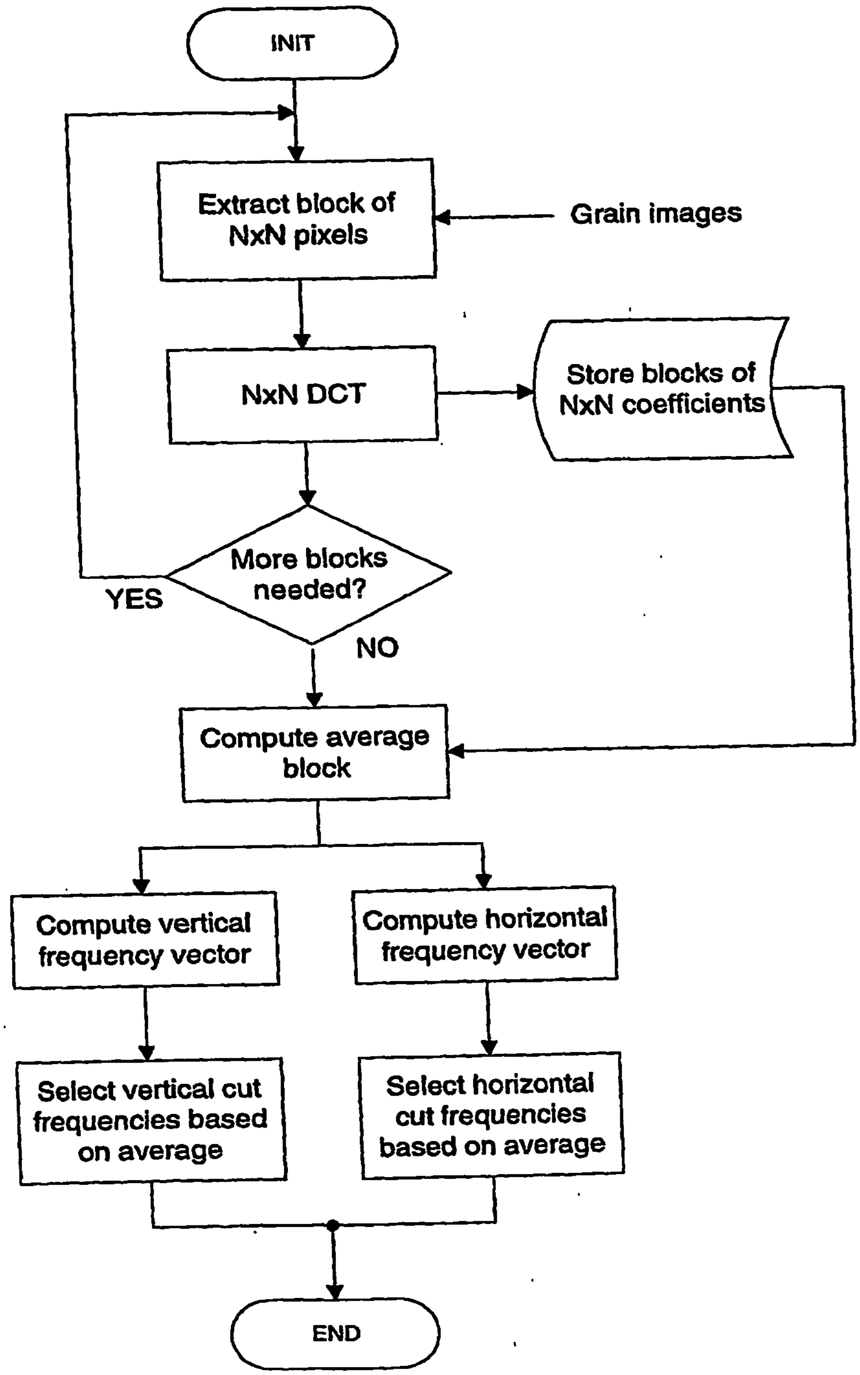

Figure 5. Estimation of the spatial correlation in the frequency domain.